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1 SUMMARY

A number of measures are used on the Hydra Gas Development Project facilities to control the process risk (safety, environmental and financial). Some of these measures are implemented using Instrumented Protective Functions (IPF).

A SIL allocation exercise has been performed over a number of workshops for the first two phases of execution of the project and is documented in the following reports:

- SIL Report (Cairo - 6th June 2013) (Ref 1)
- SIL Report (London - 14th November 2013) (Ref 2)

These workshops identified 6 loops with non-zero SIL requirements.

This document reports the analysis performed to verify that the design of the IPFs meets their SIL requirements.

The analysis found that the following IPF loops met both the architectural requirements and the reliability requirements of their allocated SIL level:

Instrument Tag	Detected Condition	Required SIL
90-PIT-001 HH	High pressure at Hydra facility inlet	2
90-PIT-010 LL	Low pressure at Hydra facility inlet	1
90-TIT-003 HH	High temperature at exit of air coolers	1
90-LIT-001 LL	Low interface level in separator	1
TI-026 HH	High temperature in wax inhibitor tank	1

The analysis found that the following IPF loop could not be confirmed as meeting both the architectural requirements and the reliability requirements of its allocated SIL level and is hence subject to HOLD. This is because this instrument, controller, and heater are within a vendor's scope of supply.

Instrument Tag	Detected Condition	Required SIL
TI-025 HH	High temperature in wax inhibitor tank heater	1

The analysis recommends that either the vendor verifies that the heater controller is certified to SIL 1, or that the SIL requirements for this trip are revisited and revised down.

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REVISIONS

Section	Change

HOLDS

Hold No.	Section	Description
1	2	Further SIL allocation work to be defined by the project
2	4	Confirmation of vendor supply controller SIL certification

ABBREVIATIONS

AIL	Asset (Commercial) Integrity Level
EGPC	Egyptian General Petroleum Company
EIL	Environmental Integrity Level
EOL	End of Line
ESD	Emergency Shut Down
FEED	Front End Engineering Design
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HIPPS	High Integrity Pressure Protection System
HS&E	Health Safety and Environmental
IEC	International Electrotechnical Commission
IPF	Instrumented Protective Function
KPC	Khalda Petroleum Company
P&ID	Piping and Instrumentation Diagram
PSV	Pressure Safety Valve
PV	Pressure Valve
SAMS	Safety Action Management System
SIL	Safety Integrity Level

2 INTRODUCTION

2.1 Project Background

Hydra is a hot, normally pressured gas condensate field located in the Western Desert of Egypt that is being developed by Khalda Petroleum Company (KPC), a joint-venture company between Apache Corporation and EGPC (Egyptian Government Petroleum Company).

The field is located approximately 21km south of the Obayied Gas Plant and to the north of the Qasr field and approximately 8km to the south west of the pipeline that runs from the Shams manifold to the Obayied Gas Plant.

Genesis has been commissioned to undertake the detailed design of Phases I and II of the Hydra Gas Development Project.

Phases I and II involve installing Hydra facilities which accommodate the fluids only in early field life when the pressures are sufficiently high to free flow to the host facilities. Fluids will be cooled and separated via a three phase separator. The separated gas and condensate will be comingled and transported to EOL for further processing via the existing Shams to EOL carbon steel pipeline. Water will be further processed and disposed of locally.

2.2 Purpose of SIL Verification

A number of measures are used on the Hydra Gas Development Project facilities to control the process risk (safety, environmental and financial). Some of these measures are implemented using Instrumented Protective Functions (IPF). It is necessary to assess the degree of reliance on these IPFs to control the risk to a tolerable level. This is a two-stage process.

In the first stage, the HAZOP, cause and effects and P&IDs are reviewed along with other necessary information to establish the required reliability of each IPF in terms of a Safety Integrity Level (SIL). This SIL allocation exercise has been performed over a number of workshops for the first two phases of execution of the project and is documented in the following reports:

- SIL Report (Cairo - 6th June 2013) (Ref 1)
- SIL Report (London - 14th November 2013) (Ref 2)
- SIL Report [Ref 3 HOLD 1]

The assessments were undertaken in line with guidance provided in IEC 61511 (Ref. 4-6), using the calibrated Risk Graph approach. This approach relies on grading a number of parameters that describe the nature of the incident and its potential impact on risk:

- Consequence severity (number and vulnerability of people affected);
- Personnel exposure;
- Alternatives to avoid danger; and
- Demand rate.

The grading has been carried out without taking credit for the IPF so that the criticality of the IPF could be established.

This report has been prepared to assess whether the design of the Hydra IPF's meet the identified requirements which is the second stage of the process.

In verifying the requirements, it is necessary to show that:

- The qualitative requirements associated with the target SIL are achieved by assessing the configuration of all IPFs with a SIL of 1 and above; and,
- The quantitative requirements associated with the target SIL are achieved by assessing the reliability of all instrumented protective functions (IPF) with a SIL of 1 and above.

2.3 Scope

The scope of this report is the verification of the IPFs identified during the SIL assessment exercises as requiring an SIL of 1 or above. These IPFs are listed in Table 2.1, along with their identified SIL requirements.

The SIL assessment carried out in June (Ref 1) identified a new requirement for a new low temperature trip on the vent drum with a SIL 1 rating. This requirement has since been deleted and is not therefore assessed.

The new LAHH interface level trip in the separator identified as requiring a SIL 0 rating has also been deleted.

IPFs deleted from the scope are listed in Table 2.2.

IPFs identified during the SIL workshops with no SIL requirement are not subject to verification. These IPFs are listed in Table 2.3.

IPFs excluded from the scope are those excluded from the SIL requirement exercises, including those associated with the fuel gas system. These IPFS are listed in Table 2.4. These IPFs will be examined as part of any future HAZOP and SIL reviews.

Table 2.1 IPFs with Allocated SIL Requirements

Instrument Tag	Detected Condition	Final Actuation Device(s) Necessary to Prevent Hazard	Required SIL	P&ID
90-PIT-001 HH	High pressure at Hydra facility inlet	ESDV-001	2	12211
90-PIT-010 LL*	Low pressure at Hydra facility inlet	ESDV-001 and ESDV-002	1	12211
90-TIT-003 HH	High temperature at exit of air coolers	ESDV-001	1	12221
90-LIT-001 LL	Low interface level in separator	ESDV-003	1	12222
TI-025 HH	High temperature in wax inhibitor tank heater	Heater Switchboard (relay)	1	12278
TI-026 HH	High temperature in wax inhibitor tank	Heater Switchboard (relay)	1	12278

* Function reassigned to a new pressure transmitter. Original assignment was to PIT-001

Table 2.2 Deleted IPFs

Instrument Tag	Detected Condition	Required SIL	P&ID
New TALL	Low temperature in vent drum	1	12261
New LAHH	High interface level in separator	0	12222

Table 2.3 IPFs with Allocated SIL Requirement of 0

Instrument Tag	Detected Condition	Required SIL	P&ID
90-VAT-001 HH	High vibration on cooler fan	0	12221
90-VAT-002 HH	High vibration on cooler fan	0	12221
90-VAT-003 HH	High vibration on cooler fan	0	12221
90-VAT-004 HH	High vibration on cooler fan	0	12221
90-LIT-015 HH	High level in cold vent drum	0	12261
90-LIT-015 LL	Low level in cold vent drum	0	12261
90-LIT-007 HH	High level in closed drains drum	0	12265
New LAHH (034)	High level in separator condensate compartment	0	12222
LI031LL	Low level in diesel storage tank	0	12251
LI023LL	Low level in methanol storage tank	0	12275
LI026LL	Low level in corrosion inhibitor storage tank	0	12276
PI067/068/087/088HH	Diaphragm failure in corrosion inhibitor pump	0	12276
FI011/017LL	Low flow of corrosion inhibitor to injection point	0	12276
LI011LL	Low level in scale inhibitor storage tank	0	12277
PI069/070HH	Diaphragm failure in scale inhibitor pump	0	12277
FI001LL	Low flow of scale inhibitor to injection point	0	12277
LI029LL	Low level in wax inhibitor storage tank	0	12278
PI071/072HH	Diaphragm failure in wax inhibitor pump	0	12278
FI012LL	Low flow of wax inhibitor to injection point	0	12278
PI059LL	Low instrument air pressure	0	12281

Table 2.4 Excluded IPFs

Instrument Tag	Reasons for Exclusion	P&ID
90-XAT-001 HH	The function of these instruments was not clear	12221
90-XAT-002 HH	The function of these instruments was not clear	12221
90-XAT-003 HH	The function of these instruments was not clear	12221
90-XAT-004 HH	The function of these instruments was not clear	12221
90-PIT-018 LL	The fuel gas system is likely to be redesigned	12241
90-PIT-018 HH	The fuel gas system is likely to be redesigned	12241
90-LIT-012 HH	The fuel gas system is likely to be redesigned	12241
90-LIT-012 LL	The fuel gas system is likely to be redesigned	12241
90-TIT-007A/B HH	The fuel gas system is likely to be redesigned	12242
90-TIT-008A/B HH	The fuel gas system is likely to be redesigned	12242

3 VERIFICATION PROCESS

3.1 Method

The individual components (sensors, logic solvers, final elements, etc.) that are working together to implement the individual instrumented function must comply with the constraints of the required integrity level. In essence this means that all components within that function must meet the probability of failure on demand (PFD), safe failure fraction (SFF) and hardware fault tolerance (HFT) requirement for the intended integrity level.

Details of the criteria which are to be met are given in 3.2.

Estimates of the SFF and HFT of each component type have been made in order to determine the minimum failure tolerant (redundant) configuration required for a given SIL. These determine the architectural requirements of the IPF.

The reliabilities of the IPFs have been determined by analysis of potential failure combinations of components which make up the IPF which would prevent execution of the intended function should a demand occur.

The probability of a particular failure combination occurring is calculated using individual component failure data, with the overall failure probability being the sum of the probability of the different failure combinations (Appendix A) in accordance with the methodology presented in the SINTEF Reliability Prediction Method for Safety Instrumented Systems (Ref 8)

3.2 Criteria

3.2.1 Architectural Requirements

The fault tolerance and SFF requirements associated with each integrity level are listed in Table 3.1 and Table 3.2. (Ref. 7)

Each device in the IPF loop must meet these requirements. Where the criteria are not met by an individual device, sufficient redundancy of the component should be provided.

Table 3.1 HFT and SFF for Simple Devices (Type A)

SFF ⁽¹⁾ (Safe Failure Fraction)	Hardware Fault Tolerance Type A ⁽³⁾ (HFT) ⁽²⁾		
	0	1	2
< 60%	SIL 1	SIL 2	SIL 3
60-90%	SIL 2	SIL 3	SIL 4
90-99%	SIL 3	SIL 4	SIL 4
>=99%	SIL 3	SIL 4	SIL 4

Table 3.2 HFT and SFF for Complex Devices (Type B)

SFF ⁽¹⁾ (Safe Failure Fraction)	Hardware Fault Tolerance Type B ⁽⁴⁾ (HFT) ⁽²⁾		
	0	1	2
< 60%	Not allowed	SIL 1	SIL 2
60-90%	SIL 1	SIL 2	SIL 3
90-99%	SIL 2	SIL 3	SIL 4
>=99%	SIL 3	SIL 4	SIL 4

Notes:

1. SFF = (Revealed Hazardous Failures + Non Hazardous Failures)/Total Failures.
2. HFT is the maximum number of faults which can occur without risk of loss of safety function e.g. a HFT of 1 means 2 faults could cause loss of the safety function, while 1 fault would not.
3. Type A components are those whose failure modes and behaviour under fault conditions are well defined, with failure rate data available.
4. Type B components are complex components for which the definition of Type A is not applicable. Programmable components are considered Type B. Type B components have lower maximum safety integrity levels due to the possibility of incomplete failure data, i.e. there may be some failure modes that may only become apparent after implementation of the component within a loop

3.2.2 Reliability Requirements

The quantitative reliability targets associated with each SIL level for low demand operations are listed in Table 3.3.

The reliability of an IPF is calculated using component device failure rate data, taking account of the device architecture. Where multiple components are employed, the reliability calculation takes into account common cause failures.

Table 3.3 Safety Integrity Level Reliability Targets

Safety Integrity Level	Probability of Failure on Demand
4	$< 1 \times 10^{-4}$ (<0.0001)
3	$1 \times 10^{-4} - 1 \times 10^{-3}$ (0.0001 - 0.001)
2	$1 \times 10^{-3} - 1 \times 10^{-2}$ (0.001 - 0.01)
1	$1 \times 10^{-2} - 1 \times 10^{-1}$ (0.01 - 0.1)

SIL requirements applicable to high demand (continuous) operation are not listed. These requirements are not applicable to the IPFs identified for Hydra.

3.3 Assumptions

3.3.1 Failure Rate Data

Equipment failure rate data has been taken from the SINTEF report, Reliability Data for Safety Instrumented Systems (Ref. 9). This data provides a consistent generic database for reliability assessment of control and safety systems. The values used are listed in Table 3.4.

Table 3.4 also shows β -factors for to be applied to the failure rates for common cause failures.

Table 3.4 Failure Rate Data

Equipment	Total Failure Rate (/ 10 ⁶ hours)	Failure to Operate (Test Detectable) ⁽¹⁾ (/ 10 ⁶ hours)	Probability of Test Independent Failure (TIF) ⁽²⁾	β -factor
Input Devices (Type A)				
Pressure Transmitter	1.3	0.3	5 x 10 ⁻⁴	0.04
Level Transmitter	3.0	0.6	5 x 10 ⁻⁴	0.04
Temperature Transmitter	2.0	0.3	5 x 10 ⁻⁴	0.04
Output Devices				
ESV/XV ⁽³⁾	5.3	2.1	1 x 10 ⁻⁴	0.03
Pilot/Solenoid	3.0	0.8	N/A	0.03
Relay	0.5	0.3	5 x 10 ⁻⁵	0.03
Control Logic and Ancillaries				
CCSS - Analogue Input ⁽⁴⁾	3.2	0.16	N/A	N/A
CCSS – CLU ⁽⁴⁾	9.6	0.48	5 x 10 ⁻⁵	N/A
CCSS - Digital Output ⁽⁴⁾	3.2	0.16	N/A	N/A
Industrial PLC – Input ⁽⁵⁾	3.6	0.7	N/A	N/A
Industrial PLC – CLU ⁽⁵⁾	17.6	3.5	5 x 10 ⁻⁴	N/A
Industrial PLC - Output ⁽⁵⁾	3.6	0.7	N/A	N/A

Notes:

1. Unsafe failures detectable by testing and repairable, i.e. physical failures

2. Unsafe failures not detectable by testing. These are functional failures such as inadequate test procedures and human error.
3. Includes valve and actuator, excludes pilot
4. Values quoted are for a SIL certified programmable safety system.
5. Assumed to be representative of the Vendor supplied control system for the wax inhibitor heater

3.3.2 Test Frequency

It is assumed that sensors, actuated elements, and elements of the control system involved in loops with a SIL rating of 1 will be subject to a full system test every 12 months.

It is assumed that sensors, actuated elements, and elements of the control system involved in loops with a SIL rating of 2 will be subject to a full system test every 6 months.

No benefit for "testing" of valves due to close demands from the control system not associated with a hazardous situation is taken.

No benefit for discrepancy monitoring of sensors is taken.

No benefit for partial stroke testing is taken.

3.3.3 Common Cause Failures

Common cause failures have been calculated according to the recommended SINTEF methodology (Ref. 5) where failure of 2 components is calculated with use of a β -factor and common cause failures of additional components are assigned probabilities directly as presented in Table 3.5.

Table 3.5 Common Cause Failure Probabilities

Number of Components Failed (N)	Conditional Probability Of Failing N+1th Component
2	0.5
3	0.6
4	0.7
5	0.8
6	0.9
7	1

These are further adjusted to take account of the configuration, e.g. M out of N, and fractional combinations thereof.

None of the loops assessed in this revision of the report (Rev B1) are vulnerable to common cause failure, and therefore these data are not applicable. However the information is retained should common mode failures be identified for IPFs for which a SIL level requirement has not yet been determined.

4 RESULTS

4.1 Minimum Hardware Failure Tolerance

The estimation of the Safe Failure Fraction (SFF) for each equipment type is presented in Table 4.1. This table also identifies the maximum SIL that can be claimed for non failure tolerant and failure tolerant configurations.

Table 4.1 Hardware Fault Tolerance of Components

Equipment	Total Failure Rate (/10 ⁶ hrs)	Failure to Operate (Test Detectable) (/10 ⁶ hrs)	SFF	Max SIL (Failure non-tolerant)	Max SIL (Failure tolerant)
Input Devices (Type A)					
Pressure Transmitter	1.3	0.3	77%	2	3
Level Transmitter	3.0	0.6	80%	2	3
Temperature Transmitter	2.0	0.3	85%	2	3
Output Devices (Type A)					
ESV/XV	5.3	2.1	60%	2	3
Pilot/Solenoid	3.0	0.8	73%	2	3
Relay	0.5	0.2	60%	2	3
Control Logic and Ancillaries (Type B)⁽¹⁾					
CCSS - Analogue Input	3.2	0.16	95%	2	3
CCSS - CPU	9.6	0.48	95%	2	3
CCSS - Digital Output	3.2	0.16	95%	2	3
Industrial PLC – Input	3.6	0.7	80%	1	2
Industrial PLC - CPU	17.6	3.5	80%	1	2
Industrial PLC - Output	3.6	0.7	80%	1	2

The table shows that all components satisfy the HFT and SFF requirements for SIL 2, with the exception of the industrial PLC taken as representative of the wax inhibitor heater controller, which satisfies the requirement of a SIL 1 system. However either it should be confirmed that the controller for the heater is certified for a SIL 1 loop, or the SIL requirements for the trip is revisited and revised down.

4.2 Reliability Assessment

The calculations of the prediction of the PFD for each IPF are presented in Appendix A and the results summarized in Table 4.2. This table presents: target SILs; the assessed PFD and corresponding SIL; and the allowable architectural SIL, based on equipment types included in the loop and maximum SILs presented in Table 4.1.

4.3 Overall Integrity Level

The overall achieved SIL is the lower of the assessed PFD SIL rating and the allowable architectural SIL.

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Table 4.2 Results Summary

Initiating Component	Calc'n Ref	Protective Function	Actuated Elements	Target SIL	Assessed PFD	Allowable Architectural SIL	Overall Achieved SIL	SIL Target Met?
90-PT-001 HH	1	Prevent Overpressure of Hydra Equipment	Close ESDV 001	2	9.4×10^{-3} (SIL 2)	2	2	Yes*
90-PT-010 LL	2	To Detect Low Pressure in Hydra Facilities Inlet	Close ESDV 001 and ESDV 002	1	2.3×10^{-2} (SIL 1)	2	1	Yes
90-TT-003 HH	3	To Detect High Temperature at Exit of Air Coolers to Limit the Temperature in the Carbon Steel Pipeline, and Hence the Rate of Corrosion	Close ESDV-001	1	1.0×10^{-2} (SIL 1)	2	1	Yes
90-LT-001 LL	4	Detect Low Interface Level In Separator to Prevent Condensate Discharge followed by Gas Blow-By to Produced Water System	Close ESDV-003	1	1.1×10^{-2} (SIL 1)	2	1	Yes
TT-025 HH	5	To Shutdown the Wax Inhibitor Heater on High Temperature	Trip Heater (Local Heater Control Trip)	1	2.5×10^{-2} (SIL 2)	HOLD 2	HOLD 2	HOLD 2
TT-026 HH	6	To Shutdown the Wax Inhibitor Heater on High Temperature	Trip Heater at Switchboard (Relay)	1	5.0E-3 (SIL 2)	2	2	Yes

*Note: SIL achieved based on a full function test every 6 months

5 REFERENCES

1. J08642A-F-RD-20006 SIL Report Rev D1
2. J08642A-F-RD-20009 SIL Report Rev B1
3. HOLD 1
4. BS IEC 61511-1, Functional Safety – Safety instrumented systems for the process industry sector – Part 1: Framework, definition, system, hardware and software requirements
5. BS IEC 61511-2, Functional Safety – Safety instrumented systems for the process industry sector – Part 2: Guidelines for the application of BS IEC 61511-1
6. BS IEC 61511-3, Functional Safety – Safety instrumented systems for the process industry sector – Part 3: Guidelines for the determination of the required safety integrity levels
7. BS EN 61508 part 2 – Function Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems
8. Reliability Prediction Method for Safety Instrumented Systems, 2010, SINTEF



6 APPENDIX A – CALCULATIONS

PFD Calculation 1 – 90-PT-001-HH

Failure Data - Pressure Transmitter				
λ	3.0E-07	β	0.04	
τ	4380	PTIF	5.0E-04	

Failure Data - Input CCSS				
λ	1.6E-07	β	N/A	
τ	4380	PTIF	N/A	

Failure Data - CCSS CLU				
λ	4.8E-07	β	N/A	
τ	4380	PTIF	5.0E-05	

Failure Data - CCSS Output				
λ	1.6E-07	β	N/A	
τ	4380	PTIF	N/A	

Failure Data - ESDV Solenoid				
λ	8.0E-07	β	0.03	
τ	4380	PTIF	N/A	

Failure Data - ESDV				
λ	2.1E-06	β	0.03	
τ	4380	PTIF	1.0E-04	

Key

	Operating On Demand
	In Failed State

PT-001	Input CCSS	CCSS CLU	Output CCSS	ESDV 001 Solenoid	ESDV 001	Independent Failures		Common Cause Failures		Test Independent Failure	
						Function	Value	Function	Value	Function	Value
						$1/2 * (\lambda * \tau)$	6.6E-04	Not Applicable	0.0E+00	PTIF	5.0E-04
						$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	1.1E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
						$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	1.8E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	4.6E-03	Not Applicable	0.0E+00	PTIF	1.0E-04
Totals							8.8E-03		0.0E+00		6.5E-04
										Overall	9.4E-03

PFD Calculation 2 – 90-PT-010-LL

Failure Data - Pressure Transmitter			
λ	3.0E-07	β	0.04
τ	8760	PTIF	5.0E-04

Failure Data - Input CCSS			
λ	1.6E-07	β	N/A
τ	4380	PTIF	N/A

Failure Data - CCSS CLU			
λ	4.8E-07	β	N/A
τ	4380	PTIF	5.0E-05

Failure Data - CCSS Output			
λ	1.6E-07	β	N/A
τ	4380	PTIF	N/A

Failure Data - ESDV Solenoid			
λ	8.0E-07	β	0.03
τ	4380 / 8760	PTIF	N/A

Failure Data - ESDV			
λ	2.1E-06	β	0.03
τ	4380 / 8760	PTIF	1.0E-04

Key	
	Operating On Demand
	In Failed State

PT-010	Input CCSS	CCSS CLU	Output CCSS	ESDV 001 Solenoid	ESDV 001	ESDV 002 Solenoid	ESDV 002	Independent Failures		Common Cause Failures		Test Independent Failure	
								Function	Value	Function	Value	Function	Value
								$1/2 * (\lambda * \tau)$	1.3E-03	Not Applicable	0.0E+00	PTIF	5.0E-04
								$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
								$1/2 * (\lambda * \tau)$	1.1E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
								$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
								$1/2 * (\lambda * \tau)$	1.8E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
								$1/2 * (\lambda * \tau)$	4.6E-03	Not Applicable	0.0E+00	PTIF	1.0E-04
								$1/2 * (\lambda * \tau)$	3.5E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
								$1/2 * (\lambda * \tau)$	9.2E-03	Not Applicable	0.0E+00	PTIF	1.0E-04
Totals									2.2E-02		0.0E+00		7.5E-04
										Overall		2.3E-02	

PFD Calculation 3 – 90-TT-003-HH

Failure Data - Temperature Transmitter				
λ	3.0E-07	β	0.04	
τ	8760	PTIF	5.0E-04	

Failure Data - Input CCSS				
λ	1.6E-07	β	N/A	
τ	4380	PTIF	N/A	

Failure Data - CCSS CLU				
λ	4.8E-07	β	N/A	
τ	4380	PTIF	5.0E-05	

Failure Data - CCSS Output				
λ	1.6E-07	β	N/A	
τ	4380	PTIF	N/A	

Failure Data - ESDV Solenoid				
λ	8.0E-07	β	0.03	
τ	4380	PTIF	N/A	

Failure Data - ESDV				
λ	2.1E-06	β	0.03	
τ	4380	PTIF	1.0E-04	

Key	
	Operating On Demand
	In Failed State

TT-003	Input CCSS	CCSS CLU	Output CCSS	ESDV 001 Solenoid	ESDV 001	Independent Failures		Common Cause Failures		Test Independent Failure	
						Function	Value	Function	Value	Function	Value
						$1/2 * (\lambda * \tau)$	1.3E-03	Not Applicable	0.0E+00	PTIF	5.0E-04
						$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	1.1E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
						$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	1.8E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	4.6E-03	Not Applicable	0.0E+00	PTIF	1.0E-04
Totals							9.4E-03		0.0E+00		6.5E-04
										Overall	1.0E-02

PFD Calculation 4 – 90-LT-001-LL

Failure Data - Level Transmitter			
λ	6.0E-07	β	0.04
τ	8760	PTIF	5.0E-04

Failure Data - Input CCSS			
λ	1.6E-07	β	N/A
τ	4380	PTIF	N/A

Failure Data - CCSS CLU			
λ	4.8E-07	β	N/A
τ	4380	PTIF	5.0E-05

Failure Data - CCSS Output			
λ	1.6E-07	β	N/A
τ	4380	PTIF	N/A

Failure Data - ESDV Solenoid			
λ	8.0E-07	β	0.03
τ	4380	PTIF	N/A

Failure Data - ESDV			
λ	2.1E-06	β	0.03
τ	4380	PTIF	1.0E-04

Key

	Operating On Demand
	In Failed State

LT-001	Input CCSS	CCSS CLU	Output CCSS	ESDV 003 Solenoid	ESDV 003	Independent Failures		Common Cause Failures		Test Independent Failure	
						Function	Value	Function	Value	Function	Value
						$1/2 * (\lambda * \tau)$	2.6E-03	Not Applicable	0.0E+00	PTIF	5.0E-04
						$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	1.1E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
						$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	1.8E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
						$1/2 * (\lambda * \tau)$	4.6E-03	Not Applicable	0.0E+00	PTIF	1.0E-04
Totals							1.1E-02		0.0E+00		6.5E-04
										Overall	1.1E-02

PFD Calculation 5 – TT-025-HH

Failure Data - Temperature Transmitter				
λ	3.0E-07	β	0.04	
τ	8760	PTIF	5.0E-04	

Failure Data - Input PLC				
λ	7.0E-07	β	N/A	
τ	8760	PTIF	N/A	

Failure Data - PLC CLU				
λ	3.5E-06	β	N/A	
τ	8760	PTIF	5.0E-05	

Failure Data - PLC Output				
λ	7.0E-07	β	N/A	
τ	8760	PTIF	N/A	

Key

	Operating On Demand
	In Failed State

Failure Data - Relay				
λ	3.0E-07	β	0.03	
τ	8760	PTIF	5.0E-05	

TT-025	Input PLC	PLC CLU	Output PLC	Relay	Independent Failures		Common Cause Failures		Test Independent Failure	
					Function	Value	Function	Value	Function	Value
					$1/2 * (\lambda * \tau)$	1.3E-03	Not Applicable	0.0E+00	PTIF	5.0E-04
					$1/2 * (\lambda * \tau)$	3.1E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
					$1/2 * (\lambda * \tau)$	1.5E-02	Not Applicable	0.0E+00	PTIF	5.0E-05
					$1/2 * (\lambda * \tau)$	3.1E-03	Not Applicable	0.0E+00	Not Applicable	0.0E+00
					$1/2 * (\lambda * \tau)$	1.3E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
Totals						2.4E-02		0.0E+00		6.0E-04
Overall										2.5E-02

PFD Calculation 6 – TT-026-HH

Failure Data - Temperature Transmitter				
λ	3.0E-07	β	0.04	
τ	8760	PTIF	5.0E-04	

Failure Data - Input CCSS				
λ	1.6E-07	β	N/A	
τ	4380	PTIF	N/A	

Failure Data - CCSS CLU				
λ	4.8E-07	β	N/A	
τ	4380	PTIF	5.0E-05	

Failure Data - CCSS Output				
λ	1.6E-07	β	N/A	
τ	4380	PTIF	N/A	

Key

	Operating On Demand
	In Failed State

Failure Data - Relay				
λ	3.0E-07	β	0.03	
τ	8760	PTIF	5.0E-05	

TT-026	Input CCSS	CCSS CLU	Output CCSS	Relay	Independent Failures		Common Cause Failures		Test Independent Failure	
					Function	Value	Function	Value	Function	Value
					$1/2 * (\lambda * \tau)$	1.3E-03	Not Applicable	0.0E+00	PTIF	5.0E-04
					$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
					$1/2 * (\lambda * \tau)$	1.1E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
					$1/2 * (\lambda * \tau)$	3.5E-04	Not Applicable	0.0E+00	Not Applicable	0.0E+00
					$1/2 * (\lambda * \tau)$	1.3E-03	Not Applicable	0.0E+00	PTIF	5.0E-05
Totals						4.4E-03		0.0E+00		6.0E-04
					Overall					5.0E-03